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P01/7700 0.00-0016591.0

# Request for grant of a patent

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06 JUL 2000

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1. Your reference P/15147.GB

2. Patent application number **0016591.0**  
(The Patent Office will fill in this part)

3. Full name, address and postcode of the or of each applicant (underline all surnames) ELCOMETER INSTRUMENTS LIMITED,  
EDGE LANE,  
MANCHESTER,  
M43 6BU, UNITED KINGDOM.

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

UNITED KINGDOM  
**6104236002**

4. Title of the invention DUAL MODE COATING THICKNESS  
MEASURING INSTRUMENT

5. Name of your agent (if you have one)  
"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode) WILSON GUNN M'CAW.,  
41-51 ROYAL EXCHANGE,  
CROSS STREET,  
MANCHESTER, M2 7BD.

Patents ADP number (if you know it) 7153927001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number	Country	Priority application number (if you know it)	Date of filing (day / month / year)

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application	Date of filing (day / month / year)

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if:

**YES**

- a) any applicant named in part 3 is not an inventor, or
  - b) there is an inventor who is not named as an applicant, or
  - c) any named applicant is a corporate body.
- See note (d))

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Continuation sheets of this form

Description

14

Claim(s)

Abstract

Drawing(s)

2 + 2

10. If you are also filing any of the following, state how many against each item.

Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (*Patents Form 7/77*)

Request for preliminary examination and search (*Patents Form 9/77*)

Request for substantive examination (*Patents Form 10/77*)

Any other documents  
(please specify)

11. I/We request the grant of a patent on the basis of this application.

Signature

Date

05/07/00

W. Usan Gunn McCar

12. Name and daytime telephone number of person to contact in the United Kingdom

MR. J.E. ROBEY - 0161-827-9400

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DUAL MODE COATING THICKNESS MEASURING INSTRUMENT

The present invention relates to a coating thickness measuring instrument particularly, but not exclusively, an instrument employing an inductive probe.

5           Conventional coating thickness measuring instruments having an inductive probe only allow thickness measurements to be made in a single limited range. A user therefore needs to select an instrument having a suitable measurement capability for his needs. If the user wishes to make measurements over a greater range than can be accommodated by a single  
10           instrument he must buy one or more additional instruments with different ranges, or at least one or more probes for a single instrument.

          Having to use more than one instrument or probe is expensive and inconvenient. The additional cost is particularly difficult to justify where a user only occasionally wishes to make measurements outside a range  
15           catered for by a single instrument or probe.

          It is an object of the present invention to address this problem.

          According to a first aspect of the present invention there is provided a coating thickness measuring instrument having a first mode of operation in which it is operative to make measurements with a first resolution and a  
20           second mode of operation in which it is operative to make measurements with a second resolution, the first resolution being greater than the second.

Provision of two such modes of operation enables the range of measurement of a given probe or instrument to be extended whilst maximising the available resolution of measurement. This will become more apparent from the following description.

5           When in the first mode the instrument is preferably operative to make measurements in a first range and when in the second mode, in a second range.

10           The second range is preferably wider than the first in which case the instrument provides a first, short range high resolution mode, and a second long range low resolution mode. The first and second ranges may be contiguous, alternatively they may overlap or the first range may be contained within the second range. It will be appreciated that where the two ranges overlap or where one contains the other measurements may be taken in the common portion of the ranges in either mode of operation, to  
15           obtain measurements of different resolution.

20           The instrument preferably comprises an inductive probe comprising a drive coil and a pickup coil, more preferably two pickup coils. The probe is preferably detachable to allow other probes to be used with the instrument. The instrument can preferably operate in either the short or long range mode with a single probe.

          The instrument preferably comprises a means to drive an alternating

current of substantially constant amplitude in the drive coil. This may comprise an oscillator and associated control loop circuit arranged to control the oscillator in dependence upon the current flowing in the drive coil. Further, there is preferably provided a means for varying the amplitude of the alternating current in the drive coil. This may comprise a digitally controlled potentiometer. This allows a desired amplitude to be set, then maintained by the control loop.

There is also preferably provided means for sensing the variation in coupling between the drive and pickup coils and converting this to a thickness value. This may comprise a differential amplifier, means for rectifying the output of the pickup coils and an analogue to digital converter. The means for rectifying may comprise a synchronous detector and may also comprise a low pass filter. The synchronous detector may be controlled by a synchronizing signal derived from the means to drive an alternating current in the drive coil. The synchronizing signal may be phase shifted relative to the alternating current in the drive coil.

In order to provide for the second range mode a means is preferably provided to modify the amplitude of the current flowing in the drive coil in dependence upon the output from the pickup coils. This means may comprise a control loop which is preferably arranged to reduce the amplitude of the current supplied to the drive coil as the differential output

of the pickup coils increases. A switch is preferably provided to enable the control loop to be switched in and out of operation, in order to switch the instrument between the first and second modes. This has the effect of flattening the response of the instrument as the probe approaches a suitable substrate, extending the range of the instrument, but reducing its resolution. Thus, the resolution of the instrument is lower in the second than first range mode, at least for measurements of a similar magnitude.

The instrument preferably includes a microprocessor. The microprocessor is preferably operative to control the amplitude of the current in the drive coil, the phase difference between the current in the drive coil and the synchronizing signal and the switch for switching in the control loop arranged to modify the amplitude of the current flowing in the drive coil.

The microprocessor is preferably also operative to generate a coating thickness value from the output of the analogue to digital converter using a look-up table. The instrument preferably also includes a memory, which may be comprised in the microprocessor, for storing look-up tables for both long and short range mode operation. The memory may also store look-up tables for other probes. Each look-up table is preferably associated with a particular probe and mode of operation.

The microprocessor may switch in the second control loop in or out



of operation at the selection of the user, or automatically upon independence of a thickness value detected. The instrument may include a user operable control, and a means for outputting information to a user, for example a display.

5           According to a second aspect of the present invention there is provided a coating thickness measuring instrument comprising an inductive probe having a drive coil and a pickup coil, a means for driving an alternating current in the drive coil, a means for detecting the output of the drive coil and a means for modifying the current in the drive coil in  
10           dependence upon the output of the pickup coil.

          Provision of a means for modifying the current in the drive coil extends the range of the instrument by allowing the gain of the instrument to be increased but preventing saturation when higher pickup coil outputs are experienced.

15           The means for modifying the current in the drive coil preferably comprises a control loop and is preferably switchable in and out of operation to provide two modes of operation for the instrument. The means for driving a current in the drive coil preferably also comprises a control loop, arranged to maintain the amplitude of the current in the drive coil at a  
20           substantially constant level. Means may be provided for setting and varying this constant level.

The means for driving may comprise an amplitude controlled oscillator with the control loop being implemented by a current to voltage rectifier, a low pass filter and an error amplifier. The means for modifying is preferably arranged to modify the input to the error amplifier and hence the amplitude  
5 of the current in the drive coil.

The means for detecting the output of the drive coil may comprise a synchronous detector.

In order that the invention may be more clearly understood an embodiment thereof will now be described by way of example with  
10 reference to the accompanying drawings in which:

Figure 1 shows a schematic block circuit diagram of a coating thickness measuring instrument according to the invention;

Figure 2 shows a schematic cross-sectional view of the probe of Figure 1 shown spaced above a substrate;

15 Figure 3 shows a block circuit diagram of the probe of Figures 1 and 2 along with some components of the circuit of Figure 1; and

Figure 4 shows a graph of the instrument's response in long and short range modes.

Referring to the drawings the instrument comprises a detachable  
20 inductive probe 1 of known type, incorporating two pickup coils 1a,1b coaxially disposed at opposite sides respectively of a drive coil 1c. The

probe 1 is detachable to enable different probes to be used with the instrument, for different applications. The probe also incorporates a tip 1d which comprises a pin which extends through the three coils 1a to 1c.

5 An amplitude controlled oscillator 2 is provided to drive a sinusoidally alternating current in the drive coil 1c of the probe 1. The amplitude controlled oscillator 2 forms part of a first control loop for controlling the current in the drive coil of the inductive probe 1. The control loop also includes a current to voltage rectifier 3 connected to the drive coil of the inductive probe and in turn to a current to voltage rectifier 3, low pass filter  
10 4, summing junction 5 and error amplifier 6 which is connected to the voltage control amplifier 2. The control loop is arranged to maintain the amplitude of the current in the drive coil of the inductive probe 1 at a substantially constant value, i.e. to stabilise the amplitude of the drive current. This constant value may be increased or decreased by modifying  
15 the voltage supplied to the error amplifier by adding or subtracting a voltage at the summing junction 5, thereby to set the amplitude of the drive current at a desired level.

The two pickup coils of the inductive probe 1 are connected to respective inputs of a difference amplifier 7 (implemented by a low noise  
20 instrumentation amplifier) the output of which is fed, in series, through a synchronous detector 8, digitally controlled gain block 9, low pass filter 10

and analogue to digital converter 11 to a microprocessor 12.

5 The microprocessor 12 controls operation of the instrument and is also connected to a digitally controlled potentiometer 13 which applies a voltage to the summing junction 5. The microprocessor 12 can thus control the amplitude of the alternating current in the drive coil of the inductive probe 1. The microprocessor 12 is also connected to a sine to square converter 14 from which it may receive a signal. The sine to square converter 14 is also connected to the drive coil of the inductive probe 1. The microprocessor is also connected to a switch 15 under control of the microprocessor and operative to bring into operation a second control loop by connecting the output of the digitally controlled gain block 9 to the voltage summing junction 5 via a low pass filter 16. In an alternative embodiment an instrument comprises an analogue control loop and a comparator based switch. The microprocessor 12 is also connected to a user operable control 17, for example a keyboard, and to display 18.

The instrument is for measuring coating thickness, particularly, but not exclusively, coating thickness on ferrous substrates.

20 To do so the instrument relies on the principle that when an alternating current flows in the drive coil of the inductive probe 1 the differential output of the two pickup coils depends upon the proximity of the probe to ferromagnetic material. The instrument has two modes of

operation: short range in which relatively high resolution thickness measurements may be taken over a limited range and long range in which thickness measurements may be made over a greater range but with a lower resolution. The mode in which the instrument is operating is controlled by  
5 the microprocessor 12, either at the selection of a user, or automatically.

When operating in short range mode the microprocessor adjusts the digitally controlled potentiometer 13, to cause an appropriate amplitude of current to flow in the drive coil of the inductive probe 1, and opens switch  
15. The instrument then operates as follows. The differential output of the  
10 two pickup coils of the inductive probe is output from the difference amplifier 7 and fed to the synchronous detector 8. The synchronous detector 8 alternately multiplies the output from the difference amplifier by positive and negative values in a manner synchronized with the output to convert the output from an a.c. signal to a full wave rectified d.c. signal.  
15 The low pass filter 10 time averages this rectified signal and removes any non synchronous signals and provides a smooth d.c. signal to the A/D converter 11.

A phase adjusted synchronization signal 19 for controlling the synchronous detector 8 is provided by the microprocessor 12. This signal  
20 is derived from the driving current of the drive coil of the inductive probe 1 by the sine to square converter 14 which supplies a square wave signal 20

to the microprocessor 12. The square wave signal 20 is synchronized with the current flowing in the probe drive coil. This signal is phase shifted by the microprocessor 12 to produce the phase adjusted signal 19. The phase shift accommodates for phase difference between the signal driving the drive coil and that detected by the pickup coils of the inductive probe 1. The phase difference for a given probe can for practical purposes be assumed to be constant. The instrument includes provision for storing a suitable phase shift value for a given probe and may store values associated with each of a number of probes which may be fitted to the instrument.

The d.c. output of the synchronous detector 8 is then amplified as appropriate by the digitally controlled gain block 9, under the control of the microprocessor 12, before being filtered by the low pass filter 10 and conversion to a digital value by the analogue to digital converter 11.

The effect of the synchronous detector 8 and low pass filter 10 is to select the signal of interest from the difference amplifier 7.

The resultant digital value is input to the microprocessor which converts it into a thickness value using a look-up table stored by the instrument. The thickness value is then displayed on the display 18. The instrument can store a number of different look-up tables for use with each of a number of different probes.

In short range mode the output of the difference amplifier 7 and

hence the digital value supplied to the microprocessor by the analogue to digital converter 11 varies very non-linearly with respect to the distance of the probe 1 from a ferromagnetic material. The relationship between the two is typically generally exponential, with the output falling as the probe 1 is moved away from a ferromagnetic material into 'free air'. This allows for high measuring resolution (typically  $0.1\mu\text{m}$ ), when the probe 1 is close to a substrate, but much lower resolution (typically  $75\mu\text{m}$ ) towards the probe's maximum usable range (typically 3mm). Thus, the range over which high resolution measurements can be made is limited.

When operating in long range mode the microprocessor 12 adjusts the digital controlled potentiometer 13 to increase the amplitude of the current supplies to the drive coil of the inductive probe 1, closes switch 15 and selects an appropriate phase shift (for the synchronous detector drive signal) and look-up table for the probe being used. Different look-up tables are required for the same probe when used in short or long range modes.

The increased amplitude of current supplied to the drive coil of the inductive probe effectively increases the gain and hence range of the instrument. Closing switch 14 brings into operation the second control loop to control the amplitude of the current supplied to the drive coil of the inductive probe 1.

Increasing the gain of the instrument alone would normally result in

the output of low pass filter 10 saturating as the probe 1 approaches a substrate, limiting the measured range. Introducing the second control loop counters this. The second control loop acts to feed a d.c. signal proportional to the probe output to the summing junction 5 where it is subtracted from the input to the error amplifier 6. Thus, the gain of the instrument is effectively reduced as the probe approaches a substrate, resulting in the output of low pass filter 10, and hence the analogue to digital converter 11, varying more linearly with distance of the inductive probe 1 from a ferromagnetic material, than when in short range mode.

The results is an increase in the overall usable range of the instrument at the expense of resolution at short distance. The typical resolution will now be  $2\mu\text{m}$  when the probe is close to a substrate and  $20\mu\text{m}$  towards the maximum usable range which is now typically 5mm.

The amount of feedback via the second control loop can be adjusted by the microprocessor 12 by adjusting the level of gain provided by the digitally controlled gain block 9. By doing so the balance between range and resolution at short distances can be altered.

Normalised d.c. output of the digitally controlled gain block for both modes of operation of the instrument is shown in Figure 3, plotted against the distance 21 of the probe tip 1d from a substrate 22. The short range mode is its normal mode of operation and achieves good lift-off sensitivity



when the front pickup coil is close to a ferromagnetic substrate material. The range of the probe in this mode is limited and its lift-off sensitivity decreases significantly with increasing values of lift-off distance. The long range mode, however, has a reduced level of lift-off sensitivity near to a  
5 ferromagnetic substrate compared to the short range mode. In this mode when the lift-off distance increases, the lift-off sensitivity does not significantly change. This results in better sensitivity (or resolution) in measuring thickness values above approximately 1mm.

The instrument may be arranged to select the appropriate mode  
10 automatically, by starting in the long range and automatically selecting short range mode if the measured thickness value falls within the range of the short range mode.

The instrument confers numerous advantages over known instruments. Provision of a secondary control loop for the drive coil of the  
15 probe extends the measuring range of a given probe with little loss of performance above the normal range of the probe. Being able to vary the probe drive coil current using a digitally controlled potentiometer allows a wide range of different probe types to be used on a given instrument. The use of a synchronous detector controlled by an appropriately phase shifted  
20 signal provided by the drive coil oscillator, and a low pass filter, reduces the potential for interference from external signals which are asynchronous to

- 14 -

that of the drive coil oscillator.

The above embodiment is described by way of example only, many variations are possible without departing from the invention.

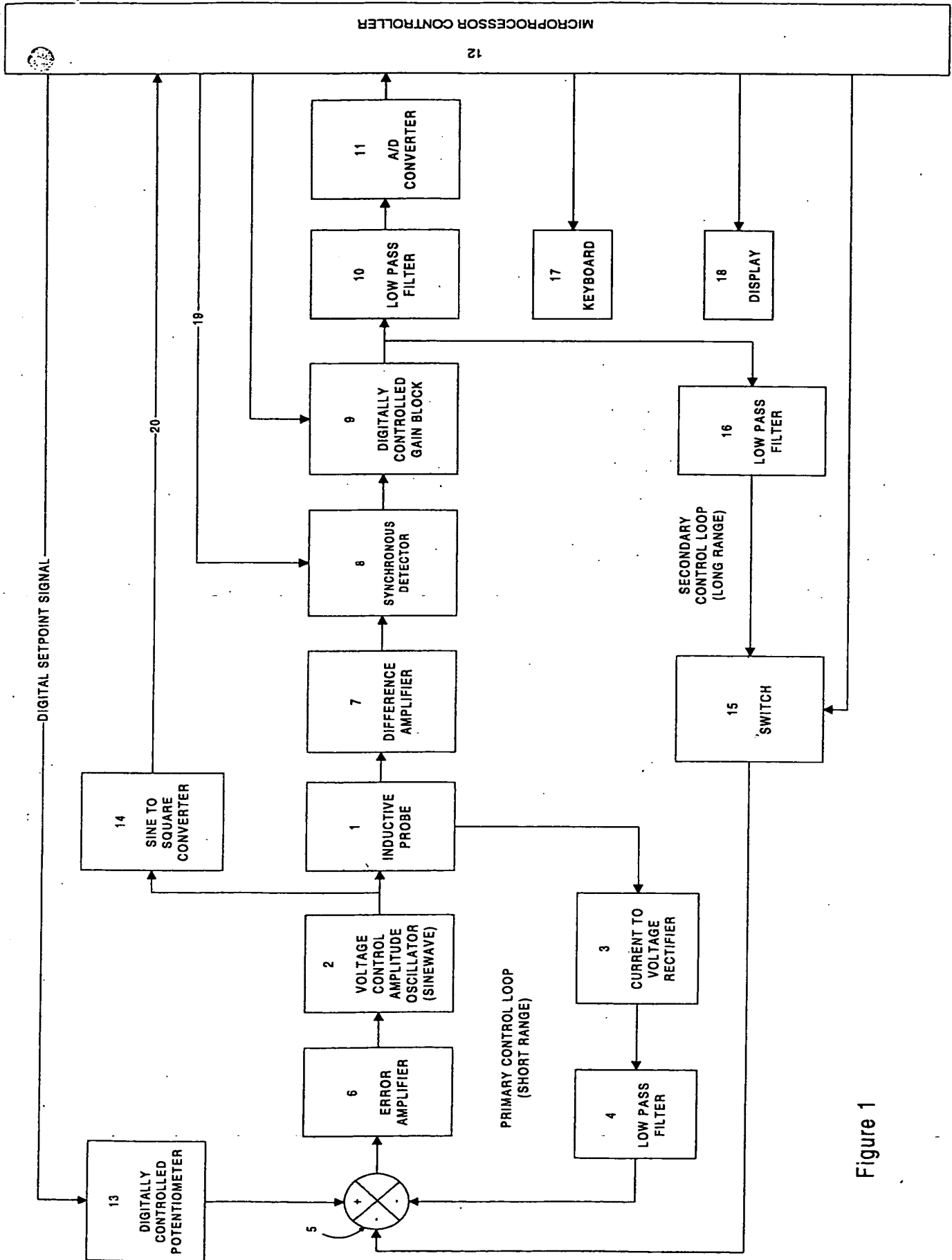


Figure 1

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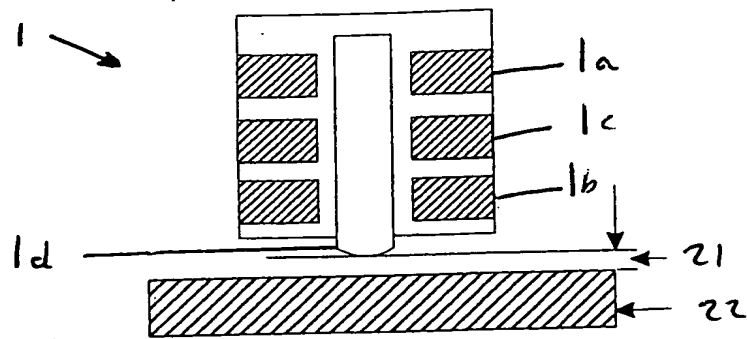


Fig 2.

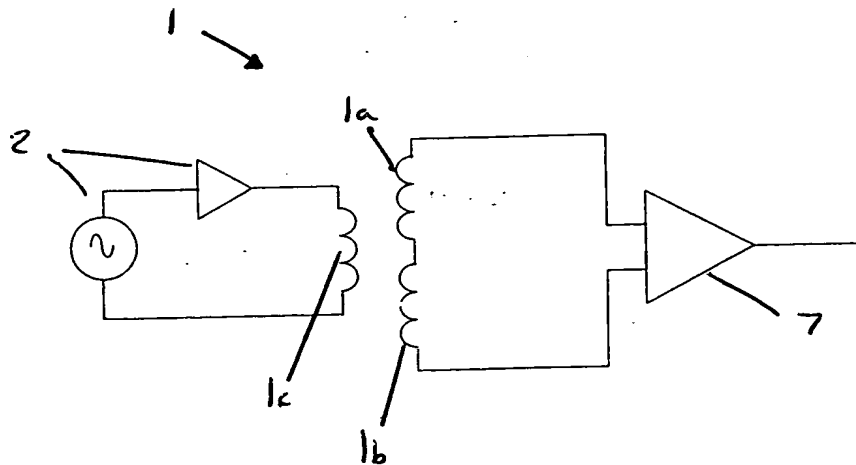


Fig 3

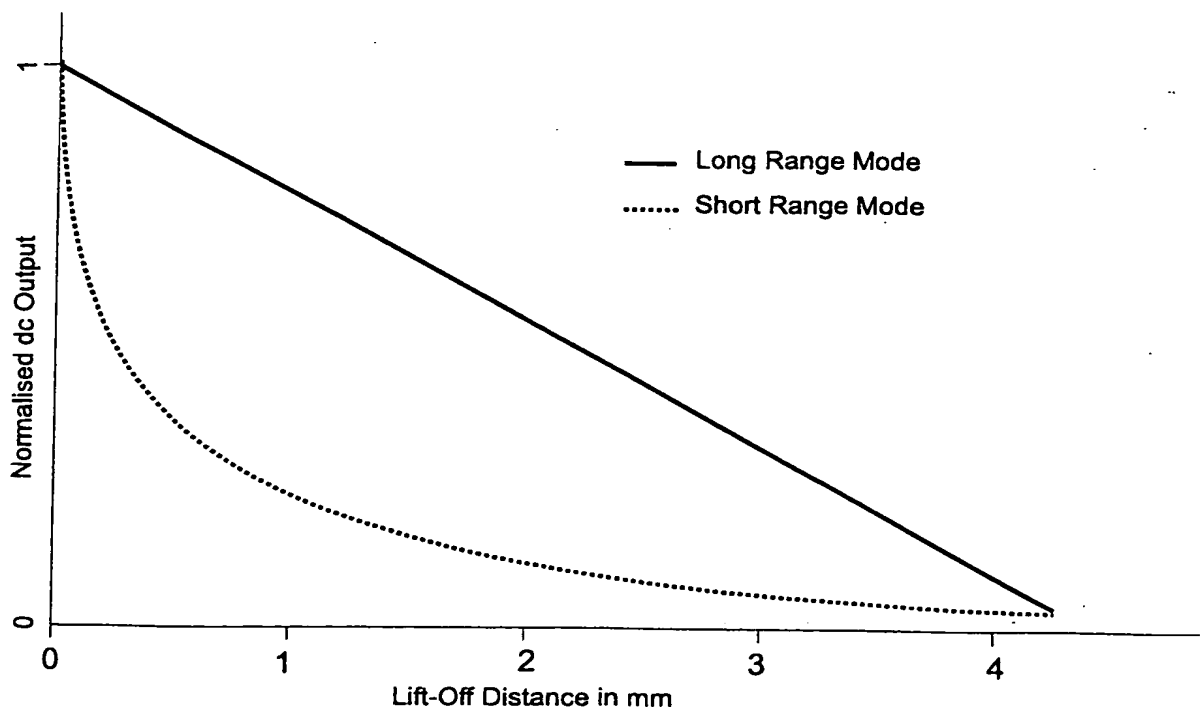


Fig 4

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